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RECORD OF REVISIONS

Rev	Date	Description	POC	OIC
0	11/18/02	General revision and addition of endnotes. Replaces Subsections 211, 214, 215, 232, 234, 241, 242, 243, 245, 246, and 247 in whole or in part.	David W. Powell, *FWO-SEM*	Kurt Beckman, *FWO-SEM*
1	5/18/05	Stated that utility distribution system components will typically be furnished and installed by the LANL SSS. Added installation requirements for indoor medium-voltage transformers. Updated references to LANL Specifications. Deleted requirement for isolated ground power for office building PC loads. Added provisions for sub-metering. Revised surge protection requirements. Changed basis for using draw-out circuit breakers to NIOSH lift calculation. Added requirement for space for future equipment additions in electrical rooms/spaces. Added zone-selective interlocking requirements. Added requirement for lower impedance dry-type transformers to serve high-harmonic loads. Added ground cable enclosed in the concrete envelope for the underground electrical service conduit(s) as a grounding electrode for renovations. Added 5-year payback criteria for replacing feeders with excessive voltage drop.	David W. Powell, *ENG-DECS*	Gurinder Grewal, *ENG-CE*

D5010 ELECTRICAL SERVICE & DISTRIBUTION

1.0 MEDIUM-VOLTAGE SERVICE & DISTRIBUTION SYSTEMS

1.1 Utility Distribution System Characteristics

A. Nominal Distribution System Voltage: 13.2 kV, 3-wire, 60 Hz.

B. System Grounding: Solidly grounded[1] at the utility substation, but not multiple grounded.

C. Load Connections: Line-to-line.

D. Short-Circuit Current: Confirm the available short-circuit current with the LANL Support Services Subcontractor electrical distribution engineer. *Guidance: LANL utility medium-voltage distribution system fault current can be as high as 18,000 amps RMS symmetrical, depending on the location and the distribution system configuration.*

E. System Configuration: *Guidance: Distribution circuits in highly developed LANL areas are generally underground with looped circuits controlled by pad-mounted sectionalizing switchgear. Major loads in such areas may have dedicated radial feeders from utility substations. Distribution circuits in less developed areas are typically aerial radial circuits.*

F. Utility distribution system components such as switchgear, transformers and cables will typically be furnished and installed by the LANL Support Services Subcontractor. Ductbanks, equipment pads, and similar construction items to support or contain utility system components will typically be furnished and installed by the Project construction contractor.

1.2 Utilization System Characteristics

A. Use medium-voltage to serve large loads such as motors 500 HP and larger.

B. Nominal Utilization System Voltage: 4160Y/2400V, 3-wire, 60 Hz or as required by the utilization equipment.

C. System Grounding: Solidly Grounded

1.3 Indoor Medium-Voltage Switchgear

A. For facility-level medium-voltage switchgear lineups and unit substation primary switchgear provide metal-enclosed interrupter switchgear[2] conforming to IEEE C37.20.3, *Standard for Metal-Enclosed Switchgear*, with current-limiting E-rated power fuses[3] conforming to IEEE C37.46*, Standard Specifications for Power Fuses and Fuse Disconnecting Switches*.

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1 System description is from 1.4.6 of IEEE Std 142™.

2 Interrupter switchgear with power fuses is a cost-effective and low-maintenance approach to protecting feeders and transformers where complex or high-speed switching is not required.

3 Current-limiting, E-rated power fuses are available for the range of short-circuit currents available on the LANL medium-voltage distribution system.

B. For facility-level medium-voltage switchgear applications that either exceed the current capacity of fused equipment or require complex or high-speed switching operations, use metal-clad switchgear with either vacuum or SF6 circuit breakers conforming to:

1. IEEE C37.20.2, *Standard for Metal-Clad and Station-Type Cubicle Switchgear*
2. IEEE C37.04, *Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis*
3. ANSI C37.06, *Standard for Switchgear—AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Preferred Ratings and Related Required Capabilities*
4. IEEE C37.09, *Standard test procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis*

C. Provide 15 kV medium voltage switchgear having the following minimum ratings:

1. 60 Hz one-minute withstand voltage at 7500 ft elevation: 36 kV (42 kV at sea level; *this rating may be obtained through insulation coordination with surge arresters*[4])
2. Basic Insulation Level (BIL) at 7500 ft elevation: 95 kV (110 kV at sea level; *this rating may be obtained through insulation coordination with surge arresters*)
3. Short circuit rating: Provide equipment with a short circuit rating greater than the available short circuit current and not less than 25,000 amps RMS symmetrical.[5]

D. Provide 5 kV medium voltage switchgear having the following minimum ratings:

1. 60 Hz one-minute withstand voltage at 7500 ft elevation: 19 kV (22 kV at sea level; *this rating may be obtained through insulation coordination with surge arresters*)
2. Basic Insulation Level (BIL) at 7500 ft elevation: 60 kV (75 kV at sea level*; this rating may be obtained through insulation coordination with surge arresters*)
3. Short circuit rating: Greater than the available short circuit current.

E. Provide intermediate-class, metal-oxide surge arresters in 13.2 kV medium-voltage switchgear conforming to IEEE Std C62.11, *Standard for Metal-Oxide Surge Arresters for Alternating Current Power Circuits*, suitable for operation at an elevation of 6001 to 12000 ft, with an RMS duty-cycle voltage rating of 18 kV.[6] Apply arresters in accordance with IEEE Std C62.22-1991, *Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems* or as recommended by the arrester manufacturer.

[4] Altitude de-rating information for medium-voltage switchgear is available from Table 5 in IEEE C37.20.3-1987 and Table 9 in IEEE Std C37.20.2-2993. 15.0 and 15.5 kV class switchgear is available with both 60 Hz one-minute withstand voltages and BIL ratings that are suitable for use at 7500 ft elevation.

[5] Minimum interrupting rating based on E-rated current-limiting fuses used in interrupter switchgear.

[6] Arrester voltage is from Table 5 in IEEE Std C62.22-1991.

1.4 Indoor Medium-Voltage Power Transformers

1.4.1 Transformer Selection:

A. Provide transformers with 13.2 kV primary with a basic impulse level (BIL) rating of 95 kV at 7500 feet elevation and a secondary BIL of 30 kV at 7500 feet elevation. De-rate all components and clearances affected by elevation for 7500 feet elevation.[7]

B. Use non-PCB "less-flammable liquid" insulated transformers conforming to IEEE Std C57.12.00, *Standard General Requirements for Liquid-Immersed Distribution, Power and Regulating Transformers,* where liquid containment for transformer oil, structural fire rating, and fire sprinkler system (0.20 gpm/sq ft) are available.[8] Use transformers having a 55/65ºC average winding temperature rise over a 30ºC average, 40ºC maximum ambient.

C. Use dry-type transformers conforming to IEEE Std C57.12.01, *Standard General Requirements for Dry-Type Distribution and Power Transformers Including Those With Solid Cast and/or Resin-Encapsulated Windings*, where liquid containment is not practical. Use dry type transformers having an 80ºC winding temperature rise over a 30ºC average, 40ºC maximum ambient. Use cast epoxy resin transformers to serve critical loads or where the transformer is in a dirty environment. Use vacuum pressure impregnated or cast epoxy resin transformers to serve non-critical loads and where the transformer is in a clean environment.[9]

D. Refer to Section G4010 for requirements and guidance for selecting outdoor transformers.

1.4.2 Transformer Capacity

A. Base transformer capacity on load calculations per the requirements in *NEC*® and this Chapter and loading guidance in the following IEEE standards as applicable:

1. IEEE C57.91-1981, *Guide for Loading Mineral-Oil-Immersed Overhead and Pad-Mounted Distribution Transformers Rated 500 kVA and Less with 65ºC or 55ºC Average Winding Rise*
2. IEEE C57-92-1981, *Guide for Loading Mineral-Oil-Immersed Overhead and Pad-Mounted Distribution Transformers Up to and Including 100 MVA with 65ºC or 55ºC Average Winding Rise*
3. IEEE C57.96, *Guide for Loading Dry-Type Distribution and Power Transformers.*

B. Use the following loading factors:

1. Average ambient temperature: Refer to Transformer Installation part of this Section.
2. Elevation: 7500 feet
3. Transformers serving facilities having a significant daily load cycle may be operated with the peak load above the transformer nameplate rating so long as normal transformer life expectancy is maintained.

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7 Dielectric strength correction factors for transformers are available in Table 1 in IEEE Std C57.12.00-1993 and Table 1 in IEEE Std C57.12.01-1989.

8 Refer to Factory Mutual *Loss Prevention Data Sheet 5-4* for guidance for locating and protecting transformers.

9 Transformer application information is from IEEE Std C57.12.01-1988, *General Requirements for Dry-Type Distribution and Power Transformers Including Those with Solid-Cast and/or Resin-Encapsulated Windings,* Section 4.2.5.

C. For single-ended services the calculated load (using *NEC*®) plus future load growth shall not exceed the calculated transformer peak loading capability. Base the secondary service conductors on the *NEC*® calculated load.

D. For double-ended services the calculated closed-tie load (using *NEC*®) plus future load growth shall not exceed the calculated forced-air peak loading capability of either transformer.

1.4.3 Transformer Overcurrent Protection

Provide primary overcurrent protection devices to provide through-fault protection of transformer in accordance with IEEE Std 242™.[10]

1.4.4 Transformer Surge Protection

Provide distribution-class, metal-oxide surge arresters in transformers with 13.2 kV primary conforming to IEEE Std C62.11, *Standard for Metal-Oxide Surge Arresters for Alternating Current Power Circuits*, suitable for operation at an elevation of 6001 to 12000 ft, with an RMS duty-cycle voltage rating of 18 kV.[11] Apply arresters in accordance with IEEE Std C62.22-1991, *Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems* or as recommended by the arrester manufacturer.

1.4.5 Transformer Installation

A. Install indoor medium-voltage transformers in accordance with the *NEC*® and the Factory Mutual Insurance Company *Loss Prevention Data Sheet 5-4*[12].

B. Provide fire-resistive vaults or rooms for indoor medium-voltage transformers.

1. Provide transformer vaults with a fire resistance rating of not less than 3 hours for liquid insulated transformers[13].
2. Provide transformer rooms with a fire resistance rating of not less than 1 hour for dry-type transformers[14].

C. Provide medium-voltage transformer vaults or rooms with outward swinging fire-rated doors[15].

1. Equip doors with panic hardware.
2. Fire rating of doors shall match fire rating of room or vault.
3. Provide door opening adequate for moving largest equipment in the room or vault.

D. Locate transformers a minimum of 36 inches from building walls[16].

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10 Refer to Section 10.8.3.2 in IEEE Std 242-1986™ for detailed information about "through-fault" protection of transformers. Similar information can also be found in IEEE Std C57.109.

11 Arrester voltage is from from Table 5 in IEEE Std C62.22-1991, *Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems*.

12 Factory Mutual *Loss Prevention Data Sheet 5-4* provides transformer installation recommendations based on test data and loss experience. FM recommendations are made LANL requirements.

13 Refer to Factory Mutual *Loss Prevention Data Sheet 5-4* clause 2.2.1.3.2.

14 Refer to *NEC*® Section 450.21(C); the *NEC*® minimum requirement for dry-type transformers over 35 kV is extended to all medium-voltage dry-type transformers at LANL.

15 Refer to *NEC*® Section 450.43; the *NEC*® minimum requirements for transformer vault doors are extended to all medium-voltage transformer rooms at LANL.

E. Provide ionization type smoke detectors and automatic sprinkler protection for indoor medium-voltage transformer vaults or rooms[17].

1. Connect ionization-type smoke detectors to the building fire alarm system.

2. Provide automatic sprinkler protection system with a discharge density of not less than 0.20 gpm/sq ft over floor area of the transformer vaults, rooms, or spaces[18].

F. Provide containment systems for transformer insulating liquid[19].

1. Provide containment with capacity sufficient for the volume of liquid in the largest transformer plus the volume of 1 hour[20] of automatic sprinkler system discharge.

2. *Curbs and/or tanks may be used to obtain the required containment volume*.

G. Provide mechanical cooling or ventilation powered from a reliable source to maintain transformer vaults or rooms within temperature limits appropriate operation of transformers at 7500 ft elevation in accordance with the following guidance:

1. Transformers may be operated based on rated kVA providing the average temperature of the cooling air does not exceed the following limits:

- *For self-cooled oil-filled transformers maintain an average ambient temperature not exceeding 81 ºF. The 81 ºF average ambient temperature covers 24 hours, and the maximum cooling air temperature during the 24-hour period must not exceed 99 ºF.*[21]

- *For forced-air-cooled oil-filled transformers maintain an average ambient temperature not exceeding 77 ºF. The 77 ºF average ambient temperature covers 24 hours, and the maximum cooling air temperature during the 24-hour period must not exceed 95 ºF.*

- *For self-cooled dry-type medium-voltage transformers maintain an average ambient temperature not exceeding 77 ºF. The 77 ºF average ambient temperature covers 24 hours, and the maximum cooling air temperature during the 24-hour period must not exceed 95 ºF.*[22]

- *For forced-air-cooled dry-type medium-voltage transformers maintain an average ambient temperature not exceeding 68 ºF. The 68 ºF average ambient temperature covers 24 hours, and the maximum cooling air temperature during the 24-hour period must not exceed 86 ºF.*

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16 Refer to Factory Mutual *Loss Prevention Data Sheet 5-4* clause 2.2.1.1.1.

17 Refer to Factory Mutual *Loss Prevention Data Sheet 5-4* clause 2.2.1.1.4.

18 Refer to Factory Mutual *Loss Prevention Data Sheet 5-4* clause 2.2.1.3.2.2; automatic sprinkler discharge density for vaults containing oil-filled transformers is extended to all transformer vaults and rooms.

19 Refer to Factory Mutual *Loss Prevention Data Sheet 5-4* clause 2.2.1.1.2.

20 1 hour sprinkler discharge requirement is based on Tables 11.2.2.1 and 11.2.3.1.1 of NFPA 13, *Standard for the Installation of Sprinkler Systems*.

21 IEEE C57.92 Table A-1 gives oil-filled transformer ambient temperature correction factors for altitude greater than 3300 ft. At 7500 ft the ambient temperature obtained by interpolation is 27.2 ºC for self-cooled transformers and 25.2 ºC for forced-air cooled transformers. Paragraph 3.5.2 sets the maximum allowable temperature at 10 ºC above the 24-hour ambient.

22 IEEE C57.96 Table 2 gives dry-type medium-voltage transformer ambient temperature correction factors for altitude greater than 3300 ft. At 7500 ft the ambient temperature obtained by interpolation is 22.4 ºC for self-cooled 80 ºC rise transformers and 19.8 ºC for forced-air cooled 80 ºC rise transformers. Paragraph 1.7.1 sets the maximum allowable temperature at 10 ºC above the 24-hour ambient.

2. *Transformers may be operated with average ambient temperature not exceeding 86 ºF (30 ºC) providing the transformer rating is reduced as described below; the 86 ºF average ambient temperature covers 24 hours, and the maximum cooling air temperature during the 24-hour period must not exceed 104 ºF:*
   - *For self-cooled oil-filled transformers reduce nameplate capacity by 5.1 percent*[23].
   - *For forced-air-cooled oil-filled transformers reduce nameplate capacity by 6.4 percent.*
   - *For self-cooled dry-type transformers reduce nameplate capacity by 3.8 percent*[24].
   - *For forced-air-cooled dry-type transformers reduce nameplate capacity by 6.4 percent.*
3. Power ventilation system from an emergency or standby power source if available[25].

1.5 Medium-Voltage Power Cable

1.5.1 Shielded 15 kV Power Cable

A. Comply with *NEC*®, IEEE C2™, ICEA S-93-639/NEMA WC-74, *Shielded Power Cables 5-56 kV* requirements for medium-voltage power cable and its installation. Use shielded power cable for 15 kV systems in raceways, duct banks, manholes, and vaults. Use shielded power cable for interconnections within switchgear and equipment where sufficient space exists for bending and terminating shielded cables. Use NRTL-listed Type MV105 power cable selected using its 90ºC ampacity[26], with copper conductors, 4/0 AWG minimum. [27]

B. Terminate shielded 15 kV cables using cable terminations that meet Class 1A requirements of IEEE 48, *Test Procedures and Requirements for High Voltage Alternating Cable Terminations* and are suitably de-rated for altitude.

C. Refer to LANL Standard Specifications Section 16124, *Medium Voltage Power Cable*, for material and installation requirements.

1.5.2 Non-shielded 15 kV Power Cable[28]

A. Use non-shielded 15 kV power cables only for short jumpers within switchgear or transformer enclosures where it is not feasible to install shielded cables due to inadequate space for bending or terminating shielded cables. Obtain approval from the LANL Electrical Authority Having Jurisdiction for each installation of non-shielded 15 kV cable.

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23 IEEE C57.92 Table A-2 gives oil-filled transformer capacity correction factors for altitudes greater than 3300 ft. At 7500 ft the capacity reduction is 5.09% for self-cooled transformers and 6.36% for forced-air cooled transformers. Paragraph 3.5.2 sets the maximum allowable 24-hour ambient temperature at 30 ºC and the maximum temperature at 10 ºC above the 24-hour ambient.

24 IEEE C57.96 Table 3 gives dry-type transformer capacity correction factors for altitudes greater than 3300 ft. At 7500 ft the capacity reduction is 3.82% for self-cooled transformers and 6.36% for forced-air cooled transformers. Paragraph 1.7.1 sets the maximum allowable 24-hour ambient temperature at 30 ºC and the maximum temperature at 10 ºC above the 24-hour ambient

25 Refer to Factory Mutual *Loss Prevention Data Sheet 5-4* clause 2.2.1.1.3.

26 Operating temperature is limited to 90C because plastic power ducts are listed for 90C conductors.

27 4/0 AWG medium-voltage cable with 5 mil tape shield is the minimum size that can carry the expected 15% of 14000 amp ground fault that will appear on the cable shield for the 0.2 seconds before the SM-149 substation breaker trips on ground fault. Source *IEEE Transactions on Industry*, Vol. IA-22, No. 6, November/December 1986 paper entitled "Are Cable Shields Being Damaged During Ground Faults?" by Paul S. Hamer and Barry M. Wood.

28 Design/installation requirements for 15 kV unshielded cable is corrective action #3 to Occurrence Report LANL-1994-0013.

B. Use non-shielded 15 kV transformer cable with 220 mils of EPR insulation, chlorosulfonated polyethylene (Hypalon) jacket, and minimum 2 AWG copper conductor.

C. Support non-shielded cables by full voltage rated, flame-resistant, non-tracking insulating materials[29] of sufficient strength, size, and placement to maintain adequate clearances. *Guidance: The following are guideline minimum clearances:*

1. *4.5 inches air separation between non-shielded cables.*
2. *4.5 inches air separation between non-shielded cables and grounded parts.*
3. *7 inches creepage distance between non-shielded cables.*
4. *7 inches creepage distance between non-shielded cables and grounded parts.*

1.5.3 Shielded 5 kV Power Cable

A. Comply with *NEC*®, IEEE C2™, ICEA S-93-639/NEMA WC-74, *Shielded Power Cables 5-56 kV* requirements for medium-voltage power cable and its installation. Use shielded power cable for 5 kV systems in raceways, duct banks, manholes, and vaults. Use shielded power cable for interconnections within switchgear and equipment where sufficient space exists for bending and terminating shielded cables. Use NRTL-listed Type MV105 power cable with copper conductors selected using its 90ºC ampacity[30].

B. Terminate shielded 5 kV cables using devices that meet Class 1 requirements of IEEE 48, *Test Procedures and Requirements for High Voltage Alternating Cable Terminations*.

C. Refer to LANL Standard Specifications Section 16124, *Medium Voltage Power Cable*, for material and installation requirements.

1.6 Raceway Systems for Medium-Voltage Cables

A. Within the perimeter of buildings install aboveground medium-voltage conductors in rigid metal conduit or intermediate metal conduit.[31] Install voltage markers on conduits as required in Section 16075, *Electrical Identification*. In areas protected with fire sprinklers terminate conduits entering equipment enclosures from above with water sealing fittings.[32] Refer to LANL Construction Specifications Section 16130, *Raceways and Boxes*, for material and installation requirements.

B. Within the perimeter of buildings install underground medium-voltage conductors in red-colored, concrete-encased duct banks providing not less than 3 inches concrete coverage and 7.5 inches center-to-center separation of ducts.[33] Refer to LANL Construction Specifications Section 02584, *Underground Ductbanks and Manholes*, for material and installation requirements.

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29 Refer to IEEE C37.20 for additional information about sheet, molded, or cast insulating materials.
30 Operating temperature is limited to 90C because plastic power ducts are listed for 90C conductors.
31 The greater wall thickness and threaded fittings of rigid metal conduit and intermediate metal conduit provide greater strength to contain the energy of a medium-voltage cable fault that EMT or PVC conduit.
32 Water sealing fittings will provide a degree of protection for electrical equipment.
33 Lesson learned from 1996 13.2 kV electrical accident at LANL. Red concrete will alert excavators that something other than a foundation is being encountered.

C. Design raceway systems for medium-voltage cables so calculated pulling tension and sidewall pressure will not exceed the cable manufacturer's recommendations. Lacking manufacturer's recommendations, use the following maximum values:[34]

1. Cable tension:
   - 0.008 lb./cmil for up to 3 conductors, not to exceed 10,000 pounds.
   - 0.0064 lb./cmil for more than 3 conductors, not to exceed 10,000 pounds.
   - 1000 lbs. per basket grip.
2. Sidewall pressure: 500 lbs./ft.

1.7 Medium-Voltage Metering

A. Where a large facility has a medium-voltage service,[35] provide an addressable, microprocessor based, multi-function digital electric meter.[36] This meter will be used for revenue metering as well as for facilities operation/maintenance purposes *Guidance: A group of buildings under the same facility management cost center may have a common primary electric meter*.

B. Provide metering equipment material and installation conforming to LANL Construction Specifications Section 16215, *Metering*.

C. Provide current transformers and fused potential transformers, conforming to ANSI C12.11, 110 kV BIL, accuracy class 0.3, of suitable ratio and burden for the connected metering systems.[37] Provide a test switch in each potential circuit and a shorting type test switch in each current circuit for connecting portable power system analyzers.

1.7.1 Provisions for Future load Growth

A. Provide floor space in each medium-voltage electrical room or space for future additions of at least one medium-voltage switchgear section with dimensions not less than the largest section. *With double-ended switchgear assemblies it may be necessary to include empty section(s) as part of the initial installation.*[38]

B. Provide each switchgear assembly with spare bus capacity not less than the percentage of future electrical load growth specified under the "Calculations" heading in Section D5000.

C. Make provisions for future overcurrent protective devices to serve the electrical load growth specified under the "Calculations" heading in Section D5000. Provide not less than one <u>space</u> to accept a device equal to the largest overcurrent protective device. Provide additional <u>spaces,</u> as may be required, sized for protective devices of the predominant size.

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[34] Criteria from Chapter 7 of the *Southwire Power Cable Manual*, 2nd Edition and are traditional design practices.

[35] An example of such a facility is the LANL Strategic Computing Complex that has a medium-voltage service with medium-voltage and low-voltage utilization equipment.

[36] Recommended practice from IEEE Std 739. Refer to Chapter 6 in the 1995 Edition for reasons for electrical metering and uses for the information obtained.

[37] ANSI C12.11, *American National Standard for Instrument Transformers for Revenue Metering 10 kV BIL Through 350 kV BIL*, covers the general requirements, metering accuracy, thermal ratings, and dimensions applicable to current and inductively coupled voltage transformers for revenue metering.

[38] Eventually, switchgear assemblies will become full, requiring the addition of new sections. This is true even for fairly new facilities and is especially prevalent in laboratory and science buildings. These future floor space provisions shall be shown on the design drawings so that space is reserved

2.0 LOW-VOLTAGE SERVICE & DISTRIBUTION SYSTEMS

2.1 System Characteristics

A. Design building service systems with appropriate voltage to cost effectively serve the load. *Refer to Clause 3.3 of IEEE Std 141™ and Clause 3.3 of IEEE Std 241™. Guidance: Select building service voltage based on estimated demand and load characteristic as follows:*

1. *Less than 50 kW demand and no 3-phase load: 120/240V, single phase.*
2. *Less than 250 kW demand and largest motor 20 HP or smaller: 208Y/120V.*
3. *More than 250 kW demand or largest motor larger than 20 HP: 480Y/277V.*
4. *Motor 500 HP or larger: Medium-voltage, refer to paragraph 1.2 in Section 5010.*

B. Unless otherwise required by the *NEC*® provide solidly grounded building service and distribution systems (e.g. 120/240V, 208Y/120V, 480Y/277V). Convert existing facilities with ungrounded service systems to solidly grounded service systems during major renovations or service equipment replacements.[39]

C. Select the grounded conductor (neutral) for services and feeders as follows:

1. If the line-to-neutral connected load is 5 percent or less of the total connected load, size the grounded conductor based on *NEC*® minimum requirements.[40]
2. If the line-to-neutral load exceeds 5 percent of the connected load, make the grounded conductor ampacity no smaller than that of the phase conductors.[41]
3. If the line-to-neutral load exceeds 57 percent of the connected load, and the circuit serves high-harmonic loads, make the grounded conductor ampacity 200 percent that of the phase conductors.[42] Coordinate the size and quantity of neutral conductors with panelboard manufacturer's installation instructions; UL 67 requires that the cable terminations for 200 percent rated neutral bars match the rating of the neutral.[43]

D. Connect utilization equipment to the service in the following manner:

1. Connect major three-phase motor and power loads at the service line-to-line voltage[44]
2. Connect HID and fluorescent lighting at the service line-to-neutral voltage.

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39 Refer to Chapter 2 in the *Soares Book on Grounding*, 7th Edition, for a detailed discussion of the pros and cons of grounded and ungrounded low-voltage distribution systems. Solidly grounded systems effectively limit and stabilize the voltage to ground during normal operation, and prevent excessive line voltages due to lightning, line surges, or unintentional contact with higher line voltages.

40 *NEC*® Article 250-24 establishes the minimum grounded conductor ampacity for services. If the service is grounded at any point, the minimum grounded conductor ampacity is 12.5% of the largest phase conductor.

41 Triplen harmonics add in the neutral, so a 7% non-sinusoidal line-to neutral load could theoretically generate a neutral current of approximately 12% (5% x 1.732) of the phase current.

42 Triplen harmonics add in the neutral, so a 57% non-sinusoidal line-to neutral load could theoretically generate a neutral current of approximately 99% (57% x 1.732) of the phase current. A 200% rated neutral path, busses, and termination/connection system is recommended practice in IEEE 1100-1999™, Section 4.5.4.2.

43 Refer to clause 12.1.6.1 in UL 67, *UL Standard for Safety for Panelboards Eleventh Edition; Contains Revisions Through and Including January 12, 2000*. For an example, refer to the Square D catalog section: "NQOD, NF, and I-Line Panelboards for Non-Linear Loads (200% Rated Neutral) Class 1630, 1670, 2110." Calling for neutral conductors with just 200% of the main bus rating may violate *NEC*® 110.3(B).

44 Refer to clause 3.3.1 in IEEE Std 141-1993™ for a discussion of low-voltage utilization voltages.

3. Connect 120V convenience receptacles, incandescent lighting, and 208V single-phase and three-phase equipment to separately derived 208/Y120V systems using dry-type step-down transformers if the service is 480Y/277V.
4. Install one or more separately derived, isolated ground power systems as appropriate to cost-effectively serve groups of computer and electronic instrument loads that are susceptible to common-mode noise. [45] Derive each isolated ground power system using a K-factor rated, dry-type transformer with electrostatic shielding between primary and secondary windings served by dedicated feeders if the service is either 480Y/277V or 208Y/120V. Susceptible computer and electronic instrument loads include:
   - Equipment within an information technology equipment room as defined in NFPA 75, *Standard for the Protection of Electronic Computer/Data Processing Equipment*.
   - Laboratory instruments communicating through coaxial cable networks.
   - Other susceptible computer and electronic loads as identified in "functional and operational requirements" or design criteria.
   - *Isolated ground power systems are not typically required for office PCs that communicate over unshielded twisted pair cables (e.g. Cat 5E) or fiber-optic cables.*
5. Connect 120V and 208V computer loads in large raised floor computer rooms to isolated-ground, separately derived 208Y/120V systems using power distribution units served by dedicated feeders if the service is either 480Y/277V or 208Y/120V.

E. Configure the low-voltage distribution system to facilitate safe work practices during maintenance and alterations[46] and to maximize power quality.

1. Connect large motor and power loads to separate services or feeders from sensitive loads.[47]
2. Provide a separate feeder for each panelboard; do not tap panelboards from a feeder riser.[48]
3. Configure system to minimize power interruptions during modifications and maintenance.[49]

2.2 Building Service Point Location

A. Locate the building service point and service equipment as close as feasible to the center of the load area. *Refer to IEEE Std 141™, Chapter 3 for additional guidance.* For LANL facilities, use the following definitions for electrical utility and service or service point, based on the configuration of the service system[50]:

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[45] Refer to clause 8.5.3.2 in IEEE Std 1100-1999™ for a detailed description of the isolated ground power system as a means to reduce common-mode noise that may interfere with electronic equipment.

[46] Refer to §2.3.1 in IEEE Std 141™ and also §5.3.2 and Chapter 9 in IEEE Std 902™ *Maintenance, Operation, and Safety of Industrial and Commercial Power Systems*.

[47] Refer to figure 8-1 in IEEE 1100-1999™ for the recommended separation of electronic load power distribution from support equipment power distribution.

[48] Tapping panelboards to a feeder riser increases the area of the building that must be shut down during maintenance to either the feeder or the panelboards.

[49] Refer to Chapter 2 in IEEE Std 141™.

[50] Definitions of supply points are necessary because a utility company does not individually serve LANL facilities. The LANL support services subcontractor serves the functions of a utility company, including operating and maintaining medium-voltage equipment up to the secondary terminals or the building supply transformers.

1. **Pad Mounted Transformer:** The utility system includes the medium-voltage (13.2 kV) distribution system and the pad mounted transformer. The service point is at the low voltage (120/240V, 208Y/120V, or 480Y/277V) terminals of the pad-mounted transformer.
2. **Secondary Unit Substation:** The utility system includes the medium voltage distribution system, the unit substation medium-voltage switchgear, and the unit substation transformer. The service point is at the low voltage terminals of the secondary unit substation transformer. The secondary unit substation may be inside or outside the building.
3. **Overhead Low-Voltage Utility Service:** The utility system includes the medium voltage distribution system, the pole mounted transformer(s), and the low voltage service drop. The service point is at the building service entrance weatherhead (or equivalent).
4. **Underground Low-Voltage Utility Service:** The utility system includes the medium voltage distribution system, the pole mounted transformer(s), and the low voltage underground service lateral. The service point is at the line terminals of the first low voltage service disconnecting means. The low voltage service disconnect may be located on the utility pole, outside the building, or inside the building.

2.3 Disconnecting Means

A. The disconnecting means for each supply permitted by *NEC*® Section 225.30 or 230.2 shall consist of a single circuit breaker or a single switch.[51]

B. Outdoor service entrance equipment (unit substation, switchboard, panelboard, or a group of safety switches) dedicated and in close proximity (*within 20 ft*) to the served structure, is defined as "equipment" that is part of the served structure. *In this case the requirements in Part II of NEC® Article 225 do not apply to the feeders and branch circuits from the outdoor distribution equipment to the structure.*[52]

C. Outdoor distribution equipment (unit substation, switchboard, panelboard, or a group of safety switches) not dedicated or in close proximity (*20 ft*) to the served structure, is defined as "another structure." In this case the requirements in *NEC*® Article 225 apply.

2.4 Metering

2.4.1 General:

Provide electrical metering for the service entrance of each building.[53] *Guidance: A group of small buildings under the same facility management cost center may have a common primary or secondary electric meter. A group of large buildings under the same facility management cost center may have a common primary electric meter.*

51 Service equipment with more than one main overcurrent device does not provide protection for the main bus.
52 The purpose for defining when equipment is "another structure" is to clarify the applicability of *NEC*® Article 225 requirements to feeders from outdoor distribution equipment.
53 Recommended practice from IEEE Std 739. Refer to Chapter 6 in the 1995 Edition for reasons for electrical metering and uses for the information obtained.

2.4.2 Revenue Meters

A. For 120/240-volt single-phase services up to, and including, 200 amperes provide a self-contained, electro-mechanical, socket-mounted kWh meter.[54] Refer to LANL Construction Specifications Section 16215, *Metering*, for material and installation requirements.

B. For three-phase services less than or equal to 800 amperes install a multi-function digital electric meter[55] that conforms to LANL Construction Specifications Section 16215, *Metering*, for material and installation and displays:

1. Real time readings (voltage, current, real power, reactive power, power factor, frequency, current and voltage distortion)
2. Energy readings (real energy, reactive energy)
3. Demand readings (demand current, demand real power, demand apparent power).

C. For three-phase services greater than 800 amperes install a switchboard mounted multi-function digital electric meter that conforms to LANL Construction Specifications Section 16215 for material and installation and displays real time readings, energy readings, and demand readings plus provides waveform capture, event capture, and trend logging.[56]

2.4.3 Instrument Transformers:

Provide current transformers and fused potential transformers, conforming to ANSI C12.11, accuracy class 0.3, of suitable ratio and burden for the connected metering systems.[57] Provide a test switch in each potential circuit and a shorting type test switch in each current circuit for connecting portable power system analyzers to monitor the electrical service. Refer to LANL Construction Specifications Section 16215 for material and installation requirements.

2.4.4 Metering Enclosures

A. If the service entrance equipment is not suitable to house meter, current transformers and potential transformers, locate a suitable metering enclosure(s) near the service entrance equipment and accessible for meter reading.

B. Provide a metal cabinet with hinged door to house the meter, test switches, fuse blocks, and terminal strips. Allow space for future installation of a telephone modem or Ethernet gateway.

C. Provide a metal cabinet for current transformers with the following minimum dimensions:

1. Service size from 300 to 600 amperes: 36” x 42” x 10”.
2. Service size from 800 to 1200 amperes: 42” x 48” x 12”.

D. Provide adequate space and access in the main electrical room for the metering enclosure(s).

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54 Small services warrant energy metering only.
55 Medium size services warrant metering that provides information in addition to energy metering that the Facility Manager can use to more efficiently operate the building.
56 Large services warrant metering that provides information related to power quality and event analysis.
57 ANSI C12.11, *American National Standard for Instrument Transformers for Revenue Metering 10 kV BIL Through 350 kV BIL*, covers the general requirements, metering accuracy, thermal ratings, and dimensions applicable to current and inductively coupled voltage transformers for revenue metering.

E. Refer to LANL Specification Section 16215 for material and installation requirements.

2.4.5 Sub-Metering

A. Configure electrical power distribution system and include provisions for future installation of sub-metering of the following loads:[58]

1. HVAC
2. Lighting
3. Computers, including PCs
4. Process loads
5. Laboratory loads.

B. Provisions for future metering include space in panelboards or pull boxes sufficient for the safe temporary installation of clamp-on or split-core current transformers.

2.5 Surge Protection

2.5.1 General[59]

A. Provide IEEE C62.41 Category C3 rated secondary surge arrester (SSA) on the line side of the service entrance disconnecting means in electrical service entrance equipment to protect each ungrounded conductor.[60]

B. Provide IEEE C62.41 Category B3 or C1 rated SSA to protect each ungrounded conductor of each power circuit that exits the structure to serve detached equipment or structures and extends more than 100 ft and is not installed underground or in metallic raceway.[61]

C. Provide UL 497B listed surge protective device for each signal, data, control, and alarm service circuit that enters the structure.[62]

D. Provide UL 497B listed surge protective device for each signal, data, control, and alarm circuit that exits the structure to serve detached equipment or structures and extends more than 100 ft and is not installed underground or in metallic raceway. Where such circuits are longer than 100 ft install UL 497B listed surge protective device at both ends of the circuit.[63]

[58] Heat loads and electrical loads for PC, process, and laboratory equipment are often significantly overestimated leading to grossly oversized mechanical and electrical equipment. This results in wasted first cost, and inefficient operation. Measured data will be used for estimating loads in future LANL buildings. Refer to *Labs21 Environmental Performance Criteria*, Energy and Atmosphere, Credit 9.

[59] NFPA 780 requires surge protection on all conductive electrical power, signal, data, and communication circuits entering or leaving buildings having lightning protection systems. Surge protection provides cost-effective reduction of lightning damage to electrical distribution and utilization equipment; therefore the NFPA requirement for surge protection is extended to all LANL facilities.

[60] Refer to 2004 Edition of NFPA 780, section 4.18.2.1.

[61] Refer to 2004 Edition of NFPA 780 section 4.18.2.3.

[62] Refer to 2004 Edition of NFPA 780 sections 4.18.2.2 and 4.18.6.1.

[63] Refer to 2004 Edition of NFPA 780 sections 4.18.2.3, and A.18.6.1.

E. Provide UL 497C listed coaxial surge protective device for each antenna and coaxial cable service line that enters the structure.[64]

F. Provide UL 497C listed surge protective device for each coaxial cable circuit that exits the structure to serve detached equipment or structures and extends more than 100 ft and is not installed underground or in metallic raceway. Where such coaxial cable circuits are longer than 100 ft install UL 497C listed surge protective device at both ends of the circuit.

G. Where the service panel directly serves electronic equipment provide IEEE C62.41 Category C3 rated transient voltage surge suppressor (TVSS) in the service equipment to protect each ungrounded conductor on the load side of the service entrance disconnecting means.[65]

H. Provide IEEE C62.41 Category B3 or C1 rated TVSS in branch circuit panelboards serving instrument or computer loads to protect each ungrounded conductor.[66]

I. Design surge protection to comply with requirements in NFPA 780 and the *NEC®*.

J. Refer to LANL Construction Specification Section 16289 *Surge Protective Devices* for material and installation requirements.

2.6 Switchgear, Switchboards, Power Panelboards

2.6.1 General

A. Distribute low voltage power from one or more circuit breaker type switchgear assemblies, switchboards, or power panelboards located in dedicated electrical equipment rooms.[67] Refer to Section 2.7 for requirements for lighting and appliance branch circuit panelboards.

B. For service entrance equipment, use low voltage switchgear, switchboards, or power panelboards that comply with *NEC®* requirements for service entrance equipment, have a single main circuit breaker[68], and are NRTL-labeled for service entrance use.

C. To compensate for the 7500-ft elevation, provide NEMA design switchboards, power panelboards, and circuit breakers rated at 600 VAC on 480V or 480Y/277V systems.[69] IEEE C37.20.1 switchgear rated 480V may be used on 480V or 480Y/277V systems.

64 Refer to 2004 Edition of NFPA 780 sections 4.18.2.2 and A.4.18.2.2.

65 IEEE Std 1100-1999™ (clause 8.6.3) recommends that facilities housing electronic equipment have service entrances equipped with listed Category C TVSSs.

66 IEEE Std 1100-1999™ (clause 8.6.4) recommends that panelboards serving electronic equipment have listed Category B SPDs.

67 LANL institutional preference is circuit breaker overcurrent protection because of its inherent capability of rapid service restoration.

68 Service equipment with more than one main overcurrent device does not provide protection for the main bus.

69 Voltage and current ratings for low-voltage equipment applied above 6000 ft must be de-rated due to the reduced insulating and heat removing properties of air. Table 10 in IEEE C37.20.1-1993 indicates the following corrections at 7500 ft elevation: voltage – 0.9763, current – 0.9953. 480V switchboards and panelboard built to NEMA standards has a maximum rated voltage of 480V; 480V switchgear built to IEEE standards has a maximum rated voltage of 508V.

D. Select low-voltage distribution system switchgear, switchboards, or power panelboards to cost-effectively serve the loads. Use the following criteria for selecting equipment:[70]

1. Mains equal to or less than 1200 amp main lugs or 800 amperes frame size main circuit breaker: NEMA PB-1, UL 67 front accessible power panelboard, front and rear aligned, branch and feeder circuit breakers panel mounted. Refer to LANL Construction Specifications Section 16442 *Panelboards* for material and installation requirements.

2. Mains greater than 1200 amperes main lugs or 800 amperes frame size main circuit breaker but all feeder circuit breakers smaller than 800 amperes frame size: NEMA PB- 2 switchboard with branch and feeder circuit breakers panel mounted. For a main circuit breaker with a weight exceeding 42-lb., use a draw-out mounted circuit breaker with RMS sensing solid-state trip unit[71]. *Some manufacturers offer fixed-mounted 1200 ampere frame-size electronic trip circuit breakers that weigh less than 42 lb.* Refer to LANL Construction Specifications Section 16441 *Switchboards* for material and installation requirements.

3. Any feeder circuit breaker 800 ampere frame size or larger with a weight exceeding 42-lb.: IEEE C37.20.1 low voltage metal-enclosed power circuit breaker (drawout) switchgear with a track-mounted hoist[72]. Use circuit breakers with RMS sensing solid-state trip units. Refer to LANL Construction Specifications Section 16426 [16430], *Low Voltage Power Circuit Breaker Switchgear,* for material and installation requirements.

E. Provide enclosures suitable for the locations where the equipment will be installed. Provide "door-in-door" fronts for indoor power panelboards.[73]

F. Provide at least the *NEC*®-required working space behind rear-accessible switchgear, switchboards, and panelboards to facilitate thermographic examination of the equipment.[74]

2.6.2 Provisions for Future load Growth

A. Provide floor/wall space in each electrical room or space for future additions of switchgear assemblies, switchboards, and power panelboards as follows:[75]

1. At least one switchgear or switchboard section with dimensions not less than the largest section. *With double-ended switchgear assemblies it may be necessary to include empty section(s) as part of the initial installation.*

2. At least one power panelboard with dimensions not less than the largest power panelboard.

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70 Equipment selection criteria are intended to promote the safe and cost-effective use of commercially available electrical distribution equipment. The criteria are intended to prevent the use of switchboards or switchgear for purposes that a power panelboard could accomplish.

71 The weight-based threshold for draw-out circuit breakers is derived from the "NIOSH Lifting Guideline". Using that guideline the calculated maximum weight for a circuit breaker that a worker should move from a dolly to a mounting position 44" above the floor is 42 lb.

72 Draw-out mounted circuit breakers that exceed the NIOSH lifting limits can be safely handled using a track-mounted circuit breaker hoist.

73 Door-in-door panelboard fronts eliminate the safety hazards associated with removing and installing panelboard fronts during troubleshooting, modification, and maintenance of panelboards.

74 Refer to LANL O&M Manual Criteria 504 – *Low-Voltage Electrical Equipment* for thermographic examination requirements and to Section 110.26(A) in the *NEC*® for working space requirements.

75 Eventually, panels will become full, requiring the addition of new panels. This is true even for fairly new facilities and is especially prevalent in laboratory and science buildings. These future wall and floor space provisions shall be shown on the design drawings so that space is reserved

B. Provide each switchgear assembly, switchboard, and power panelboard with a percentage of spare bus capacity not less than the percentage of future electrical load growth specified under the "Calculations" heading in Section D5000.

C. Make provisions for future overcurrent protective devices to serve the electrical load growth specified under the "Calculations" heading in Section D5000. Provide not less than one space to accept a circuit breaker with frame size equal to the largest feeder circuit breaker. Provide additional spaces, as may be required, sized accept circuit breakers of the predominant feeder circuit breaker frame size.

1. In new power panelboards and switchboards provide spaces to accept the future circuit breakers.
2. In low-voltage power circuit breaker switchgear assemblies provide completely outfitted draw-out circuit breaker cubicles to accept the future circuit breakers.

2.6.3 Overcurrent Protection

A. Provide switchgear, switchboards, and power panelboards with bus bracing and overcurrent device interrupting ratings that exceed the calculated available short-circuit current.[76] Refer to the "Calculations" heading in Section D5000.

1. Where possible, use circuit breakers with the required NRTL-listed interrupting ratings.[77]
2. Where necessary, use current-limiting circuit breakers to obtain required interrupting ratings higher than those obtainable with "high-interrupting" circuit breakers. [78]
3. *Where current-limiting circuit breakers are not available, current-limiting fuses may be used to obtain the required interrupting rating.*
4. Do not use series-rated circuit breakers except to obtain an integrated short-circuit rating within a switchboard or panelboard.[79]

B. Provide individual overcurrent protection on the supply side of each switchgear, switchboard, and power panelboard; overcurrent protection may be either a dedicated upstream feeder circuit breaker or a main circuit breaker.[80]

C. Provide selectively coordinated overcurrent protection.[81] Refer to the "Calculations" heading in Section D5000.

D. Use zone selective interlocking as described in IEEE Std 242™ within and between the following equipment:[82]

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[76] Refer to section 110.9 in the *NEC®*.

[77] Circuit breakers can usually be re-set after the fault has been investigated and cleared; no spare parts, such as fuses, are required.

[78] Current-limiting circuit breakers are available with 200 kA interrupting rating from 20 to 600 amperes.

[79] Manufacturers obtain series ratings through testing of specific circuit breaker designs; series ratings are not generally available for one manufacturer's circuit breaker with another manufacturer's product. Within a switchboard or panelboard it is possible to maintain the correct series-rated circuit breakers; it is unlikely that this control would be maintained beyond the switchboard or panelboard.

[80] The basic requirement in Section 408.36(B) of the *NEC®* is extended to switchgear, switchboards, and power panelboards to improve constructability, maintainability, and safety, and also to reduce the number of users disturbed when maintenance, repairs, or modifications are performed in distribution equipment.

[81] Refer to Chapter 5 in IEEE Std 141™.

[82] Zone selective interlocking provides improved personnel and equipment protection as follows: When a downstream breaker (feeder) detects a fault, it signals the upstream device (main) to shift to its preset time delay band, allowing

1. Low-voltage power circuit breaker switchgear assemblies.
2. Switchboards with electronic trip circuit breakers.

E. When ground-fault protection is required for the service disconnecting means on 480Y/277V services, provide an additional step of ground-fault protection in the next level of feeders.[83] Use the following guidance for selecting ground fault protection settings:

1. *Service disconnect rated 1000 amperes*[84] *or more: Set ground fault pickup at 1200A, 0.5 second delay.* [85]
2. *Feeder devices set at 100 amperes or less (long-time setting): ground fault protection not required.*[86]
3. *Feeder devices set at over 100 amperes up to 1200 amperes (long-time setting): Set ground fault pickup equal to 0.8 times the feeder device trip setting, 0.3-second delay.* [85]
4. *Feeder devices set at over 1200 amperes (long-time setting): Set ground fault pickup at 1000 amperes, 0.3 second delay.*
5. *Consider using zone selective interlocking to minimize the arcing ground fault damage that may occur in the switchgear.* [85]

2.7 Lighting & Appliance Branch Circuit Panelboards

2.7.1 General

A. Serve branch circuits using lighting and appliance branch circuit panelboards that meet the requirements of UL 67, *Panelboards*; UL 50, *Enclosures for Electrical Equipment*; NEMA PB1, *Panelboards*; *NEC*® and LANL Construction Specifications Section 16442, *Panelboards*.

B. Locate lighting and appliance branch circuit panelboards as close to the center of the load area and on the same floor as the loads served according too the following criteria:[87].

1. Maximum branch circuit voltage drop: 3 percent[88]
2. Maximum 208Y/120V system branch circuit length: 100 ft [89]

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the downstream device to clear the fault while the upstream device provides backup protection. If a fault occurs between two breakers equipped with zone selective interlocking, the upstream breaker would clear the fault on the minimum delay band because it receives no interlock signal from a downstream breaker, thus minimizing the duration that the fault would exist before being cleared.

83 Ground-fault protection on both the service and feeders is required to provide fully selectively coordinated ground-fault protection. A ground fault on a feeder should not cause the service ground fault interrupter to operate. Refer to FPN No. 2 in section 230.95 in the *NEC*®.

84 Ground fault protection is required on 480Y/277V system service disconnects rated 1000 amperes or more. Refer to section 230.95 in the *NEC*®.

85 Refer to 8.3.4 in IEEE Std 242-2001™ for additional guidance in setting ground fault protection devides.

86 Electronic trip circuit breakers rated smaller than 70 or 100 amperes are not commonly available from commercial sources. It is anticipated that the available arcing ground fault current will be of sufficient magnitude to trip circuit breakers 100 amperes and smaller before the main ground fault protection operates.

87 IEEE Std 141™, Chapter 3 establishes guidance and analysis methods for maximum circuit lengths.

88 Voltage drop criteria are mandatory provisions in ASHRAE/IESNA Standard 90.1-1999.

89 100 ft is the approximate maximum circuit length serving a 120V 16-ampere, 0.95 pf line-neutral load through a magnetic conduit with 12 AWG conductors in a balanced multi-wire circuit or with 10 AWG conductors in a 2-wire circuit with 3% voltage drop.

3. Maximum 480Y/277V system branch circuit length: 230 ft [90]

C. Where more than 50% of the panelboard connected branch circuit load is third harmonic-generating line-to-neutral connected equipment (such as PCs and monitors), provide panelboard with a 200% rated neutral bus.[91]

D. Provide two typed 8-1/2” x 11” circuit directories for each panelboard as shown in Figure 5010-1. *Guidance: Panelboard schedules produced by commercial software may be used if the same information is provided.*

1. Provide a printed copy and an electronic copy to the Facility Manager.[92]
2. Mount a plastic laminated copy inside the panelboard door.[93]

E. Arrange the single-phase loads between all phases of each panelboard to obtain phase currents balanced to within 15 percent of the average of the phase currents.[94]

2.7.2 Lighting Panelboard Feeders

A. Provide individual overcurrent protection on the supply side of each lighting and appliance branch circuit panelboard, using either a dedicated feeder circuit breaker or a main circuit breaker for each panelboard.[95]

B. Where more than 50% of the panelboard branch circuit connected load is third harmonic-generating line-to-neutral connected equipment (such as PCs and monitors), provide feeder to panelboard with a 200% rated grounded conductor.

C. Refer to Section 5020 for the number of PC stations and the unit loads that are to be included in feeder and service load calculations.

2.7.3 Lighting Panelboard Circuit Breakers

A. Use thermal-magnetic circuit breakers that conform to UL 489, *Molded Case Circuit Breakers*, and NEMA AB 1, *Molded Case Circuit Breakers and Molded Case Switches*.

B. Use 600V two-pole or three-pole circuit breakers in 480V and 480Y/277V panelboards. [96]

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[90] 230 ft is the approximate maximum circuit length serving a 277V 16-ampere, 0.95 pf line-neutral load through a magnetic conduit with 12 AWG conductors in a balanced multi-wire circuit or with 10 AWG conductors in a 2-wire circuit with 3% voltage drop.

[91] Refer to Figure 8.5 and §8.4.2.3 in IEEE Std 1100-1999™. The requirement for 200% rated neutral bus is driven by the effect that switched-mode power supplies have on transformers. With more than a small portion of the load being switched-mode power supplies, K-rated transformers with 200% neutral connections are needed.

[92] The Facility Manager will use the circuit directory to keep up-to-date records of circuit changes for both configuration management purposes and to facilitate lock-out/tag-out procedures.

[93] The standard panelboard circuit directory card is too small to legibly record the purpose of each circuit breaker (type and location of each branch circuit load) as required in *NEC*® Article 408.4.

[94] The purpose of load balancing is to keep voltage unbalance within 2 percent. Refer to clause 3.8 in IEEE Std 141™ for a discussion of phase-voltage unbalance in three-phase systems.

[95] The basic requirement in Section 408.36 of the *NEC*® is invoked to improve constructability, maintainability, and safety, and also to reduce the number of users disturbed when maintenance, repairs, or modifications are performed.

[96] Voltage and current ratings for low-voltage equipment applied above 6000 ft must be de-rated due to the reduced insulating and heat removing properties of air. Table 10 in IEEE C37.20.1-1993 indicates the following corrections at 7500 ft elevation: voltage – 0.9763, current – 0.9953. 480V switchboards and panelboard built to NEMA standards has a maximum rated voltage of 480V; 480V switchgear built to IEEE standards has a maximum rated voltage of 508V.

C. Provide panelboard circuit breakers with NRTL-listed interrupting ratings that exceed the calculated available short-circuit current. [76, 77]

1. Where necessary, use current-limiting main circuit breakers to obtain integrated panelboard interrupting ratings higher than those of standard circuit breakers.
2. Do not use series-rated circuit breakers except to obtain an integrated short-circuit rating within a panelboard.

2.7.4 Provisions for Future load Growth

A. Provide floor/wall space in each electrical room or space for the future addition of at least one lighting and appliance branch circuit panelboard.[97]

B. Provide each panelboard with a percentage of spare bus capacity not less than the percentage of future electrical load growth specified under the “Calculations” heading in Section D5000.

C. In each panelboard provide a percentage of spare single-pole 20-ampere circuit breakers not less than the percentage of future electrical load growth specified under the “Calculations” heading in Section D5000.

D. Install circuits from each of the spare circuit breakers to accessible pull boxes located above the panelboard. Install not more than three circuits to each bull box.

E. Schedule single pole spaces to fill out each panelboard to 24, 30, or 42 space units.[98]

2.7.5 Isolated Ground Panelboards

A. Provide power for computer and electronic instrument loads susceptible to common-mode noise as described in 2.1 of this Section using dedicated isolated ground panelboards on a separately derived, isolated-ground power system.[99]

B. Isolated ground panelboards shall be 208Y/120V, 3-phase, 6- wire systems with an insulated isolated ground bus (IG), un-insulated equipment ground bus (EG), and a 200 percent rated grounded conductor (neutral) bus. The isolated ground bus shall have the same rating as the phase buses.[100]

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97 Eventually, panels will become full, requiring the addition of new panels. This is true even for fairly new facilities and is especially prevalent in laboratory and science buildings. These future wall and floor space provisions shall be shown on the design drawings so that space is reserved

98 Spare circuit breakers and open breaker spaces facilitate the orderly expansion of electrical use in the facility.

99 Refer to clause 8.5.3.2 in IEEE Std 1100-1999™ for a detailed description of the isolated ground power system as a means to reduce common-mode noise that may interfere with electronic equipment.

100 Refer to clause 8.4.2 in IEEE Std 1100-1999™ for recommendations for panelboard bussing when serving high-harmonic loads.

Figure 5010-1 Panelboard Schedule

LIGHTING PANEL "LP2"

MAINS: 100 AMP MAIN LUGS
VOLTAGE: 208Y/120V, 3 PH, 4 W.
SERVED BY: 3-410-XFMR2 LOCATION: TA-3-410-123
SHORT CIRCUIT RATING: 8250 AMPS, RMS, SYMMETRICAL
LOCATION: TA-3-410-120
MOUNTING: SURF SECT. 1

SERVES	C/B	CONT	RCPT	PWR	CKT	PHASE	CKT	CONT	RCPT	PWR	C/B	SERVES
RCPT RM 101	1P20		1440		1	-A-----	2		1440		1P20	RCPT RM 102
RCPT RM 103	1P20		1440		3	---B---	4		1440		1P20	RCPT RM 104
RCPT RM 105	1P20		1440		5	-----C-	6		1440		1P20	RCPT RM 106, 108
RCPT RM 107	1P20		1440		7	-A-----	8		1440		1P20	RCPT RM 110
RCPT RM 109	1P20		1440		9	---B---	10		1440		1P20	RCPT RM 112
RCPT RM 111	1P20		1440		11	-----C-	12		1440		1P20	RCPT RM 114
	3P /			440	13	-A-----	14			1000	3P /	
VACUUM PUMP	/			440	15	---B---	16			1000	/	OUTLET FOR LASER
RM 111	/ 15			440	17	-----C-	18			1000	/ 20	Rm 114
LIGHTS RM 113	1P20	1200			19	-A-----	20		1440		1P20	RCPT RM 113
WELDER OUTLET	2P/			1800	21	---B---	22		1440		1P20	RCPT RM 100
RM 113	/30			1800	23	-----C-	24		1440		1P20	RCPT RM 115
SPARE	1P20				25	-A-----	26				1P20	SPARE
SPARE	1P20				27	---B---	28				1P20	SPARE
SPARE	1P20				29	-----C-	30				1P20	SPACE

TOTAL CONNECTED PHASE VOLT-AMPS: A: 9840 B: 10440 C: 10440

CONNECTED:			DESIGN:		
CONTINUOUS LOAD (CONT):	1200	VA	CONTINUOUS LOAD @ 125%:	1500	VA
RECEPTACLE LOAD (RCPT):	21600	VA	RECEPT. LOAD PER NEC 220-13:	15800	VA
NON-CONT. POWER LOAD (PWR):	7920	VA	POWER LOAD @ 100%:	7920	VA
	---		20% SPARE CAPACITY:	5044	VA
TOTAL CONNECTED LOAD:	30720	VA	TOTAL DESIGN LOAD:	30264	VA
	85.3	AMPS		84.1	AMPS

2.7.6 Power Distribution Units

Provide power for computer equipment in raised floor computer rooms using factory-fabricated power distribution units. Power distribution units are free-standing cabinets that are located on the raised floor and contain one or more isolated ground panelboards, an electrostatic shielded transformer, surge protection devices, and metering and control apparatus. [101]

2.8 Low-Voltage Dry-Type Transformers

2.8.1 General-Purpose Dry-Type Transformers

A. Use dry-type transformers as described below to derive system voltages for general-purpose loads where the switched-mode power supply load is less than 20% of the total connected load.[102]

1. Where the average daily load will be less than 50% of the transformer nameplate rating use an ENERGY STAR labeled transformer that complies with NEMA TP-1, *Guide for Determining Energy Efficiency for Distribution Transformers*. [103] *ENERGY STAR labeled transformers will typically be used for loads in office buildings and similar occupancies.*

2. Where the average daily load will be 50% or more of the transformer nameplate rating use a low temperature rise dry-type transformer (115 °C rise or less). *Low temperature rise transformers will typically be used for process loads in laboratory buildings.*

B. Refer to LANL Construction Specifications Section 16461 *Dry-type Transformers* for material and installation requirements.

2.8.2 Transformers for Switching Mode Power Supply Loads

A. Where more than 20% of the transformer connected load is harmonic-generating line-to-neutral connected equipment (such as PC switch mode power supplies), provide K-Factor rated, shielded isolation, dry-type distribution transformers specifically designed for non-linear loads such as office equipment and PC switched-mode power supplies.[102, 104]

B. Select transformer K-factor based on manufacturer's recommendations and the following guidance:[105]

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[101] Refer to clause 8.5.3.2 in IEEE Std 1100-1999™ for a detailed description of the isolated ground power system as a means to reduce common-mode noise that may interfere with electronic equipment.

[102] Refer to Figure 8-5 in IEEE Std 1100-1999™. The capacity of conventional transformers must be de-rated when the switched-mode power supply load becomes more than a small part of the transformer connected load.

[103] Executive Order 13123, *Greening the Government through Efficient Energy Management,* Sec. 403 (b.1) directs agencies to select, where life-cycle cost-effective, ENERGY STAR and other energy efficient products when acquiring energy-using products.

[104] Refer to clause 8.4.1 in IEEE Std 1100-1999™ for recommended practice for use of electrostatically shielded and K-factor rated dry-type transformers to serve electronic load equipment. K-factor relates a transformer's ability to serve non-linear load without exceeding the rated temperature-rise limits.

[105] K-factor guidelines lifted from manufacturers' recommendations and NAVFAC Specification Section 16400, Service and Distribution.

1. *Use K-4 rated transformers when load is a large number of non-linear single-phase electronic equipment. An example is an isolated ground separately derived system serving 20 or more personal computer stations in an office environment.*
2. *Use K-13 rated transformers when connected loads are comprised of single, large electronic loads, or small numbers of comparatively large single-phase loads. Examples are mainframe computers, on-line single-phase UPS systems, and isolated ground separately derived systems serving less than 20 personal computer stations.*
3. *Caution should be used in specifying K-ratings above K-13, as the impedance generally decreases as the K-ratings increase. This low impedance can result in unexpectedly high line-to-line and line-to-ground fault currents.*
4. *K-factor rated transformers should never be used for three-phase non-linear loads such as motor drives, three phase UPSs, or any three-phase device with SCR phase-control or static-diode input circuits.*

C. Select transformer impedance based on the following:[106]

1. Where more than 20% of the panelboard connected load is harmonic-generating line-to-neutral connected equipment (such as PC switch mode power supplies), provide transformers with impedance not exceeding 6%.
2. Where more than 50% of the panelboard connected load is harmonic-generating line-to-neutral connected equipment (such as PC switch mode power supplies), provide transformers with impedance not exceeding 5%.

D. Refer to LANL Construction Specifications Section 16461, *Dry-Type Transformers*, for material and installation requirements.

2.8.3 Transformers for Three-Phase Converter Loads

A. Use dry-type transformers as described below to derive system voltages or to provide isolation for three-phase converter loads such as UPS loads, solid-state motor drive loads, and similar loads that generate high 5th and 7th harmonics or the current pulse stresses of three-phase converter loads.

B. Provide transformers that are specifically compensated and tested per UL 1561 procedures for the typical harmonic spectrum of phase converters defined in IEEE-519, *Standard Practices And Requirements For General Purpose Thyristor Drives.*[107]

C. Drive isolation transformers must be capable of supplying the drive overload requirements defined as Class B in IEEE-597, and be suitable for 150% load for one minute occurring once per hour.

[106] Refer to IEEE Std 1100-1999™ for recommended practice for low-voltage dry-type transformer impedances. Low impedance transformers are required to minimize voltage waveform distortion due to nonlinear load equipment.

[107] Information about special requirements for transformers serving three-phase converter loads is from the 1996 Square D "Dry-Type Transformers Selection Guide".

2.8.4 Transformer Loading

A. Provide each transformer with a percentage of spare capacity not less than the percentage of future electrical load growth specified under the “Calculations” heading in Section D5000.

B. Including the spare capacity described above, load transformers to no more than 97.5 percent of the sea-level nameplate rating when used in an environment where the average ambient temperature for any 24-hour period does not exceed 86 ºF (30 ºC), and the maximum cooling air temperature during the 24-hour period does not exceed 104 ºF (40 ºC).[108]

C. Transformers may be operated at nameplate rating where there is sufficient ventilation or mechanical cooling to maintain an average ambient temperature less than 83.3 ºF (28.5 ºC). The 83.3 ºF average ambient temperature shall cover 24 hours, and the maximum cooling air temperature during the 24-hour period shall not exceed 92.75 ºF (33.75 ºC).[109]

D. Where it is not possible to provide the average 86 ºF ambient temperature, de-rate dry-type transformer kVA capacity in accordance with ANSI/IEEE C57.96, Table 1.

2.8.5 Transformer Installation

A. Locate transformers as close as practicable to the switchboard, panelboard, or loads served.[110]

B. Provide primary and secondary overcurrent protection for each transformer as described in the *NEC*®; protect the transformer primary and secondary conductors at their ampacity. [111]

C. Design transformer secondary conductors and connections so they can be safely installed, tested, and maintained.[112]

1. Where possible, terminate the transformer secondary conductors in a single circuit breaker located within 25 ft (wire length) of the secondary terminals.[113]
2. Avoid making taps to transformer secondary conductors in a wireway or wiring trough.

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[108] NEMA ST 20, Table 5-1 gives dry-type transformer kVA correction factors for altitude greater than 3300 ft with an ambient temperature of 30C. The kVA correction factor for 7500 ft is 97.5%.

[109] NEMA ST 20, Table 5-1 gives dry-type transformer ambient temperature correction factors for altitude greater than 3300 ft. At 7500 ft the ambient temperature correction factor is 0.950, and the maximum cooling air temperature is 33.75 ºC.

[110] IEEE Std 1100™, section 8.3.2.2.3 recommends that transformers be located as close as practicable to the branch circuit panelboard and the loads served.

[111] The primary circuit breaker provides short-circuit protection for the primary conductors and a degree of overload protection for the transformer, and the secondary circuit breaker(s) prevent the transformer and secondary conductors from being overloaded. Without secondary overcurrent protection, primary overcurrent protection must be not more than 125% of the rated transformer primary current—refer to *NEC*® Table 450.3(B); such a low overcurrent device will sometimes trip on the transformer magnetizing inrush current.

[112] Lesson learned form several LANL design-build construction projects.

[113] Using a single secondary overcurrent protective device improves worker safety by reducing arc-flash energy that would be available during a short circuit on the main bus. Also, main lug power panelboards do not inherently limit the number circuit breakers that can be installed as secondary protection to the NEC limit of six or the sum of multiple breaker ratings to the total that would be permitted for a single circuit breaker.

D. Provide adequate space for ventilation around transformers. Provide not less than 6 inches separation between any transformer ventilation opening and any obstruction. Do not locate transformers above heat-producing equipment unless positive and reliable compensating measures are provided.[114]

2.9 Grounding

2.9.1 General

Install the grounding systems in accordance with *NEC*® Article 250, IEEE Std. 142™, IEEE Std 1100™, LANL Construction Specifications Section 16060 *Grounding and Bonding* and as described in this section. Electrical Drawings ST-D5010-1 and ST-D5010-2 illustrate the grounding system requirements.

2.9.2 Grounding Electrode System

A. Install the grounding electrode systems having calculated ground resistances not exceeding the following values:

1. Aggregate service rated 50 kVA and less: As required by the *NEC*®.[115]
2. Aggregate service rated more than 50 kVA but less than 2500 kVA: 5 Ohms[116]
3. Aggregate service rated 2500 kVA and larger: 1 Ohm[117]

B. Perform calculations of grounding electrode resistance using methods outlined in IEEE Std. 142™.[118] Since soil resistivity at LANL ranges from 1,800 to 140,000 Ohm-cm within one mile[119], the design professional must investigate and determine the soil resistivity for each site.[120] *Guidance: A recommended method is to have soil resistivity measurement part of the geotechnical report, using the Wenner four-electrode method and procedures described in ASTM G57.*

C. For new structures install a concrete-encased main grounding electrode in the lower part of the perimeter strip footing or grade beam to form a complete loop around the building.[121] Use one of the following materials for the electrode:

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[114] Clearance data is collected from manufacturer's installation instructions.
[115] Refer to *NEC*® article 250.
[116] 5 Ohms is indicated in clause 4.1.2 of IEEE Std 142-1991™ as suitable ground electrode system resistance for industrial plants and large commercial installations.
[117] 1 Ohm is indicated in clause 4.1.2 of IEEE Std 142-1991™ as suitable ground electrode system resistance for large industrial plants, substations, and generating stations.
[118] Chapter 4 of IEEE Std 142-1991™ describes methods for calculating ground electrode resistance.
[119] In 1999 soil resistivity measurements were made at LANL using the Wenner Four-Point method on roughly a one-mile grid. Measurements at the 4-ft depth ranged from 2,100 to 93,000 Ohm-cm. There was no consistent relationship of soil resistivity to location.
[120] Clause 4.1.3 in IEEE Std 142-1991™ strongly recommends that the resistivity of the earth at the desired location of connection be investigated.
[121] The concrete encased electrode used at LANL is based on that described in clause 4.2.3 of IEEE Std 142-1991™.

1. Use a bare copper ground cable not smaller than the grounding electrode conductor required in the *NEC*® and not smaller than 4 AWG.[122]
2. Use bare or galvanized perimeter concrete reinforcing bars that are made electrically continuous. Use reinforcing bars not smaller than the following based on the total length of the interconnected and paralleled reinforcing bars[123]:

Total length of reinforcing bars	Minimum reinforcing bar
112 ft	1 3/8” (#11 bar)
150 ft	1” (#8 bar)
192 ft	3/4” (#6 bar)
223 ft	5/8” (#5 bar)
268 ft	1/2” (#4 bar)

Interconnect reinforcing bars using bare copper jumpers that are either exothermically welded to the reinforcing bars or connected using hydraulically compressed tap fittings that meet requirements of IEEE 837, *Standard for Qualifying Permanent Connections Used in Substation Grounding*.[124] Use jumpers that are neither smaller than the required *NEC*® grounding electrode conductor nor smaller than 4 AWG.

D. For new structures bond each perimeter structural steel column to the main grounding electrode described above.[125]

1. Use bond conductors that are not smaller than the grounding electrode conductor required in the *NEC*® and not smaller than 4 AWG.
2. Make bonding connection to either directly to the steel column or a column anchor bolt using either an exothermic weld or a hydraulically compressed fitting that meets IEEE 837 requirements.

E. For modifications to existing structures measure the ground resistance of the existing main grounding electrode and verify that the electrode system is adequate and substantial.

1. Verify that the main grounding electrode is a separate electrode from that used for lightning protection.[126]
2. Install one or more of the following supplemental grounding electrode(s) to obtain the required ground resistance or to establish a main grounding electrode that is separate from the lightning protection ground:

[122] Section 250.52(A)(3) in the *NEC*® sets 4 AWG as minimum size concrete-encased grounding electrode and Table 250-66 establishes the minimum size grounding electrode conductor (or rebar jumper) based on service conductor size. The concrete-encased ground electrode (or rebar jumper) is made the same size as the electrode conductor because it is considered the main grounding electrode.

[123] Minimum sizes for concrete-encased electrode rebars are based on Table 15 in IEEE Std 142-1991™ and assuming a 5-cycle clearing time for a 30 kA ground-fault or lightning event. Size of rebar is critical to ensure that high magnitude ground currents do not damage the concrete surrounding the rebar.

[124] These methods of making grounding electrode connections are described in clauses 4.3.3 and 4.3.5 in IEEE Std 142-1991™.

[125] This method of bonding to perimeter building columns is described in clause 4.2.3 of IEEE Std 142-1991™.

[126] Section 250.60 in *NEC*® requires that the electrical system grounding electrode be separate from (but bonded to) the lightning protection grounding electrode.

- A bare copper ground cable not smaller than the grounding electrode conductor required in the *NEC*® and not smaller than 2 AWG, not less than 20 feet long, and buried not less than 30 inches deep adjacent to the building foundation in a Bentonite[127] slurry backfill.[128]
- One or more electrolytic ground rods installed in accordance with the manufacturer's instructions.
- A bare copper ground cable, not smaller than the grounding electrode conductor required in the *NEC*® and not smaller than 4 AWG, not less than 20 ft long where outside the building perimeter, and enclosed in the concrete envelope for the underground electrical service conduit(s).[129]

F. Install a main grounding electrode bar adjacent to the service entrance equipment; use the main grounding electrode bar as a point for bonding all grounding electrodes, power systems, separately derived systems, communications systems, piping systems, and structural steel.[130]

1. Refer to LANL Construction Specifications Section 16060 *Grounding and Bonding* for ground bar material and installation requirements.
2. Connect the grounding electrode bar to the main grounding electrode using unspliced copper cable and irreversible connections. Irreversible connections are either exothermic welds or IEEE Std 837 compression lugs attached with tamper-proof nuts and bolts.[131]
3. Install main grounding electrode bar extensions at additional locations in reinforced concrete structures for grounding separately derived systems that are remote (more than 50 ft) from the main grounding electrode bar.[132] Establish main grounding electrode bar

[127] Bentonite is a natural clay containing the mineral montmorillionite, which was formed by volcanic action years ago. It is noncorrosive, stable, and has a resistivity of 2.5 .·m at 300% moisture. The low resistivity results mainly from an electrolytic process between water, Na2O (soda), K2O (potash), CaO (lime), MgO (magnesia), and other mineral salts that ionize forming a strong electrolyte with pH ranging from 8 to 10. This electrolyte will not gradually leach out, as it is part of the clay itself. Provided with a sufficient amount of water, it swells up to 13 times its dry volume and will adhere to nearly any surface it touches. Due to its hygroscopic nature, it acts as a drying agent drawing any available moisture from the surrounding environment. Bentonite needs water to obtain and maintain its beneficial characteristics. Its initial moisture content is obtained at installation when the slurry is prepared. Once installed, bentonite relies on the presence of ground moisture to maintain its characteristics. Most soils have sufficient ground moisture so that drying out is not a concern. The hygroscopic nature of bentonite will take advantage of the available water to maintain its as installed condition. If exposed to direct sunlight, it tends to seal itself off, preventing the drying process from penetrating deeper. It may not function well in a very dry environment, because it may shrink away from the electrode, increasing the electrode resistance

[128] Supplemental electrode based on clause 10.7.2 in the 1999 New Mexico Electrical Code adapted to LANL site specific requirements.

[129] Modifications to existing structures often include installation of new underground electrical service.

[130] Interconnection of building grounding electrodes and other systems is described in clause 8.5 and figure 8-6 in IEEE Std 1100-1999™.

[131] The intent of the requirement for irreversible connections is so connections to the main grounding electrode bar can be considered the same as direct connections to the main grounding electrode.

[132] Reinforced concrete structure buildings do not have electrically continuous structural steel for grounding separately derived systems as required in Section 250.30 of the *NEC*®.

extensions by installing ground bars connected to the main ground electrode bar using unspliced 4/0 AWG copper cable with irreversible connections.[133]

4. Connections to the main grounding electrode bar (or extensions) will be considered direct connections to the main grounding electrode.
5. Label each connection to the main grounding electrode bar or extensions.[134]

G. Bond building structural steel, interior metallic piping systems, and exterior metal water piping systems to the main grounding electrode bar using copper cable, listed pipe clamps, exothermic welds, and compression lugs that meet requirements of IEEE Std 837. Use bonding conductors that are not smaller than the grounding electrode conductor required in the *NEC*® and not smaller than 4 AWG.

H. Bond the lightning protection grounding counterpoise to the building grounding electrode system at the main grounding electrode bar using 600V insulated 4/0 AWG ground cable and compression lugs that meet IEEE Std 837 requirements.[135]

2.9.3 Circuit and System Grounding

A. Connect the service entrance equipment ground bus to the main grounding electrode bar with unspliced grounding conductor sized per *NEC*® Table 250.66.[136]

B. In the service entrance equipment, connect the system grounded conductor bus to the equipment ground bus with a bonding jumper sized per *NEC*® Table 250.66; do not use a factory furnished bonding screw.

C. Separately Derived Systems (transformers, generators, computer power distribution units, UPS, etc.):

1. Ground separately derived systems in the vicinity (within 50 ft) of the main electrical room to the main grounding electrode bar.
2. Ground separately derived systems remote from the main electrical room to the nearest effectively grounded building structural steel or metal water pipe within 5 ft of the point of entrance into the building.[137] If neither grounding electrode is available, install a main grounding electrode bar extension near the separately derived system disconnecting means.

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[133] The intent of the requirement for 4/0 AWG cable with irreversible connections is so connections to the main grounding electrode bar extensions can be considered the same as direct connections to the main grounding electrode bar.

[134] Labels on connections to the main grounding electrode bar will reduce the possibility of disconnecting the wrong system ground during facility maintenance or modifications.

[135] Clause 3-14.1 requires that main size lightning conductors be used to interconnect the grounding electrode systems. 4/0 AWG is used for the lightning protection counterpoise conductor. Conductor insulation is to prevent uncontrolled interconnection of electrodes.

[136] Section 250.24(A)(4) in the *NEC*® permits connecting the grounding electrode conductor to the equipment ground bar if main bonding jumper is a wire or busbar.

[137] Refer to *NEC*® Section 250.30(A)(7).

3. Connect the separately derived system equipment ground bus at the first system disconnecting means or overcurrent device to the ground described above using unspliced grounding conductor sized per *NEC*® Table 250.66, based on the derived system conductor size.[138]
4. At the separately derived system disconnecting means or overcurrent device, connect the system grounded conductor bus to the equipment ground bus with a bonding jumper sized per *NEC*® Table 250.66; do not use only a factory furnished bonding strap or bonding screw.[138, 136]
5. Bond the grounded conductor to all interior metallic piping systems in the area served by the separately derived system in accordance with *NEC*® requirements.[139]

2.9.4 Enclosure and Equipment Grounding

A. Install an NRTL-listed equipment ground bar or ground lug in each item of electrical equipment and bond it to the equipment enclosure.[140]

B. Install a 600 volt insulated (green) equipment ground conductor in each feeder raceway.[141] An equipment-grounding conductor is not required in a service entrance raceway if the service includes a system grounded conductor.

C. Provide feeder and plug-in busways with integral low-impedance grounding conductor having an ampacity not less than 50 percent of the busway and with plated, low-resistance contact areas at busway joints and connection points.[142]

2.9.5 Isolated Grounding System

A. Install isolated grounding systems for computer and laboratory instrument power systems that are susceptible to common-mode noise.[143] Refer to Section 2.1 of this Chapter for guidance in establishing isolated ground power systems.

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138 LANL institutional preference is to make the connection between the separately derived system grounded conductor and the equipment-grounding conductor in the enclosure for the first overcurrent device. This was codified in AHJ Interpretation No. 003 dated January 24, 1995. The connection point in the first disconnect or overcurrent device is the preferred location because these enclosures are more likely to have standard arrangements incorporated into their design for this connection. Required inspection and testing of the ground on an energized system can be accomplished with less risk to personnel in the overcurrent device enclosure than in the transformer enclosure.

139 The bonding requirement in *NEC*® Section 250.104(A)(4) to bond metallic water piping systems is extended to all metallic piping systems in the area served by the separately derived system to provide additional safety.

140 A listed ground bar or ground lug provides an acceptable place to terminate the equipment grounding conductor(s). In many instances at LANL mounting screws or sheetmetal screws have been used to terminate equipment grounding conductors; thus creating potential electrocution hazards.

141 Installation of an insulated equipment-grounding conductor is recommended practice in clause 8.5.3 of IEEE Std 1100-1999™. Clause 2.2.3 of IEEE Std 142-1991™ indicates that the use of a metal raceway as a grounding conductor supplemented by an equipment grounding conductor achieves both minimum ground fault impedance and minimum shock hazard voltage.

142 An integral ground conductor that completely enclose the busway conductors have a lower 60 Hz impedance than provided by internal ground

143 The purpose of isolated ground power systems is to reduce common mode noise that may interfere with sensitive electronic equipment. Isolated ground power systems are described in clause 8.5.3.2 of IEEE Std 1100-1999™.

B. In addition to the equipment ground bar, install an insulated isolated ground bar in switchboards and panelboards supplying isolated ground circuits. [144]

C. At the first isolated ground system phase conductor overcurrent device or disconnecting means, bond the isolated ground bus to the equipment ground bus with a bonding jumper sized per *NEC*® Table 250.66; do not use a factory furnished bonding strap or bonding screw. Make no other isolated ground to equipment ground connections. [138, 136]

D. In addition to the equipment-grounding conductor, install a dedicated 600-volt insulated (green/yellow) isolated ground conductor for each isolated ground feeder.

1. Make isolated ground conductors the same size as the phase conductors.[145]
2. Connect the isolated ground conductors to the isolated ground bars in switchboards and panelboards.

2.10 Raceway Systems

A. Use raceway systems to contain all low-voltage service and distribution wiring.

B. Install raceways that are sized with consideration given to all conductor adjustment factors required by the *NEC*®.

C. Install conduits according to the following limits of bends and distance between pull points:

- Fifty feet (50') with three (3) equivalent 90 degree bends;
- One hundred feet (100') with two (2) equivalent 90 degree bends;
- One hundred fifty feet (150') with one (1) 90 degree bend;
- Two hundred feet (200') straight run, when field conditions permit.

When field conditions will not permit conduit to be installed to the above requirements, cable-pulling calculations will be required.

D. Design raceway systems for low-voltage cables so calculated pulling tension and sidewall pressure will not exceed the following values:[146]

1. Cable tension:
   - 0.008 lb./cmil for up to 3 conductors, not to exceed 10,000 pounds.
   - 0.0064 lb./cmil for more than 3 conductors, not to exceed 10,000 pounds.
   - 1000 lbs. per basket grip.
2. Sidewall pressure: 500 lbs./ft.

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144 Recommended practice for isolated ground systems is provided in clause 8.5.3.2 of IEEE 1100-1999™.
145 Clause 8.5.3 in IEEE Std 1100-1999™ indicates that the isolated ground conductor is the sole grounding path from electronic load equipment to the power system or the separately derived system. To provide a low ground fault impedance and minimum shock hazard voltage, LANL institutional preference is to make the isolated ground conductor the same size as the phase conductors.
146 Criteria from Chapter 7 of the *Southwire Power Cable Manual*, 2nd Edition and are traditional conservative practices.

E. Indicate sizes of conduits, wireway sections, and cable tray sections on the construction or record as-built drawings.

F. Refer to LANL Construction Specification 16111, *Conduit*, for raceway material and installation requirements.

G. Provide concrete-encasement and warning tape for underground low-voltage service and feeder conduit outside the perimeter of the building. Provide warning tape for underground low-voltage service and feeder conduit inside the perimeter of the building. Provide not less than 7.5 inches center-to-center separation of conduits.[147] Provide not less than 3 inches concrete coverage on all sides. *Guidance: Low-voltage service and feeder conduits inside the perimeter of the building need not be concrete-encased.*

H. Refer to LANL Construction Specification 16130, *Boxes*, for material and installation requirements for junction and pull boxes.

I. In addition to locations required by the *NEC*®, provide conduit sealing fittings with approved sealant at the following locations:

   1. Where conduits cross the boundary of a radiological area.[148]
   2. Where conduits pass between areas where air pressure differential must be maintained.

J. Install raceways penetrating radiation shielding or permanent contamination zones with sufficient bends, curvature, or shielding to prevent radiation streaming through the void.[149]

2.11 Conductors

2.11.1 Wiring Color Codes

A. Identify all wiring system conductors at each accessible location using color-coding that is consistent throughout the building.[150] *Guidance: For minor work[151] in existing facilities use wiring color codes that match existing color codes so long as National Electrical Code® requirements for identifying grounded and grounding conductors are satisfied[152].*

B. Refer to LANL Construction Specifications Section 16120, *Building Wire and Cable,* for the wiring color codes.

C. Install a permanent placard on the enclosure for each switchgear assembly, switchboard, panelboard, motor control center, dry-type transformer, safety switch, and motor controller.

[147] Refer to Figure 310.60 in the *NEC*®.
[148] The purpose of sealing raceways crossing radiological areas is to prevent the spread of contamination.
[149] DOE 6430.1A, section 1300-6.2, Shielding Design, states that straight-line penetration of shield walls shall be avoided to prevent radiation streaming.
[150] Color coding of phase conductors will facilitate identification of system voltages and correct installation of equipment that requires a particular phase rotation, such as motors.
[151] Refer to ESM Chapter 7, D5000, 1.0-E.4.
[152] Refer to *NEC*® Sections 200.6 and 250.119.

On the placard indicate the color code for each conductor in the enclosure by phase and voltage.[153]

2.11.2 Building Wire and Cable

A. Use copper conductors that have been sized with consideration to adjustment factors for voltage drop, temperature, raceway fill, harmonics, and future loading.[154]

B. Indicate on the construction or record as-built drawings the number and size of conductors in conduit runs, wireway sections, and cable tray sections.

C. Refer to LANL Construction Specifications Section 16120, *Building Wire and Cable,* for materials and installation methods.

D. Use minimum 12 AWG and maximum 500 kcmil copper conductor for all power wiring.[155] Consult with the ESM Electrical POC before using conductors larger than 500 kcmil.

E. For new construction work size service and feeder conductors to limit the total voltage drop from service point to the most remote outlet to 5%. Design branch circuit conductors for a maximum voltage drop of 3% at full connected load. Design feeder conductors for a maximum voltage drop of 2% at full connected load.[156] Include voltage drop in service conductors in the 5% total voltage drop. Use calculation methods outlined in Chapter 3 of IEEE Std 141™.

F. For renovation work replace service and feeder conductors that otherwise meet *NEC*® requirements if the energy savings from meeting the above voltage drop limits will yield a simple 5-year payback of the replacement costs.[157]

G. Size feeders serving switchgear, switchboards, motor control centers, and panelboards to at least match the load bus or load circuit breaker rating.[158]

H. In areas where the total integrated gamma dose for the useful life of the facility is calculated to be 10^6 rads or greater, such as hot cells, provide conductor insulation such as cross-linked copolymer, polyvinyl chloride, or polyethylene. Radiation doses will be specified in the project design criteria.[159]

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[153] The requirement for placards indicating conductor color codes is extended from multi-wire branch circuits in *NEC*® Section 210.5 (D) to all conductors at LANL.

[154] Adjustments for raceway fill, ambient temperature, and harmonics are required in *NEC*® Article 310-15.

[155] The use of minimum 12 AWG on branch circuits limits voltage drop. 500 kcmil is the largest conductor that can be terminated in copper circuit breaker lugs.

[156] AHSRAE/IESNA Standard 90.1-1999 requires the stated voltage drop design criteria.

[157] Lesson learned from LANL construction projects. 5 years simple payback is a common acceptance criterion for energy-saving investments.

[158] Matching the load bus to the feeder ampacity reduces uncertainty in the field about the true capacity available at panelboards, switchboards, transformers, etc.

[159] Gamma radiation can cause deterioration of the physical and electrical properties of polymers used in conductor insulation materials. Refer to IEEE 1205, *IEEE Guide for Assessing, Monitoring, and Mitigating Aging Effects.*